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Estimate of catch of shortfin mako caught by Japanese squid driftnet fishery between 1981 and 1992 in the North Pacific.[1]

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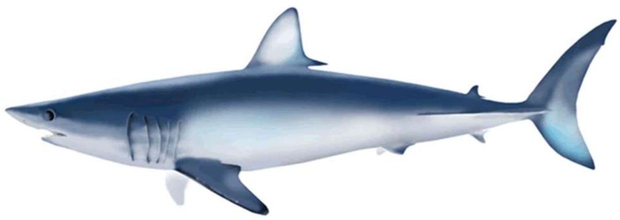

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Abstract

The catch of shortfin mako (*Isurus oxyrinchus*) caught by Japanese squid driftnet fishery in the North Pacific between 1981 and 1992 at high seas was estimated, following the methodology used for blue shark in 2021 (Fujinami et al. 2021). Catch of sharks in the logbook data was species aggregated ("sharks") and the zero-catch rate of sharks was high, so that the annual catch of shortfin mako was estimated from the standardized CPUE of observer data and logbook data. The annual catch (in number) ranged from 55 (1981) to 1,768 (1988), corresponding to 2.1 in 1981 to 67.6 ton in 1988. The estimated catch of squid driftnet fishery was much smaller than that of large-mesh driftnet fishery. This may be partly because lower overlap between fishing area of this fishery and core distribution area of shortfin mako shark than that of large-mesh driftnet fishery. In general, catch by "Japanese driftnet fishery" fleet, combining updated catch of large-mesh driftnet (Semba and Kai 2023b) and current estimate, was much lower than catch of F12 in previous assessment in 2018. Although further improvement is necessary to be continued, this indicates the impact of driftnet fishery before 1993 might be lower than assumed previously.

Introduction

In the North Pacific, shortfin mako (*Isurus oxyrinchus*, hereafter indicated as SMA) has been caught as bycatch by various type of fishery in Japan. Domestically, landing by longline dominated (80% of total shortfin mako landed) and the ratio of catch by driftnet fishery is 17% (Semba and Kai 2023a). Before the introduction of moratorium for high sea driftnet fishery in 1993, Japan had two types of driftnet fishery, consisting of large mesh driftnet and squid driftnet fishery at high seas.

Japan introduced driftnet fishery for squid (main target: *Ommastrephes bartramii*) in 1978 and this fishery expanded rapidly due to its high efficiency. Along with its expansion, concern was raised about the impact of these fishery on ecosystem, such as bycatch of sharks, seabirds, and marine mammals. Impact on blue shark was estimated by several studies (e.g., McKinnell and Seki 1998; Ichii et al. 2017), and the amount of bycatch was also estimated (Yatsu et al. 1993), but the information on the impact for SMA by this fishery at high seas before 1993 is scarce. In case of Japan, logbook data between 1981 and 1992 and observer data between 1990 and 1991 were available, regarding Japanese squid driftnet fishery before the moratorium.

As indicated in the report of last stock assessment of SMA (ISC Shark Working Group 2018), the catch for the early period (1975-1993) was highly uncertain because species-specific catch was not reported for major fisheries. In case of SMA, no detailed information on the method for the estimation of catch was available both for large-mesh driftnet and squid driftnet fishery. Regarding the catch of SMA by "driftnet fishery", it was included as "F12" in the last stock assessment by stock synthesis. If it was estimated by converting the catch of blue shark by this fishery estimated in the stock assessment of blue shark in 2009 (Kleiber et al. 2009), F12 includes catch of both large-mesh and squid driftnet fishery. As this estimate in 2009 assessment was also uncertain in terms of method and materials for the estimation, and unreasonable constant value was assumed for some years, the catch of blue shark by Japanese driftnet fishery was updated in the stock assessment of blue shark in 2022, (Fujinami et al. 2021a, b). Considering the same problem in SMA, it is necessary to update the catch of shortfin mako by this fishery, at least, using the same approach. The aim of this document is to estimate the catch of SMA by Japanese squid driftnet between 1981 and 1992, based on observer and logbook data of squid driftnet fishery.

Materials and methods

Data Source

1. Logbook data

Logbook data of squid driftnet was available between 1981 and 1992. In this data, information was aggregated by three types of periods (10-day period) in each month (1 for 1-10, 2 for 11-20, 3 for 21-31). The year, month, location (latitude and longitude), number of operations, number of standardized tans deployed and catch in weight (kg) of several species per each period were included. Detail description of this dataset is described in Fujinami et al. (2021). Regarding sharks, all species were aggregated, and the zero-catch ratio of sharks was considerably high (approximately 80%) on a basis of fishing operations for 10 days (Fujinami et al. 2021).

2. Scientific observer data

Scientific observer data on board for squid driftnet vessel was available between 1990 and 1991. In this data, information was aggregated by each set and contains detailed information on each set; date (year, month, day, time) and location (latitude and longitude) of operation, environmental condition (meteorological condition, sea surface temperature, and wave height) at the time of driftnet deployment and retrieval, gear configurations (mesh size, number of deployed nets, length of one net) and catch in number of all species caught by the driftnet fishery (Fujinami et al. 2021).

Regarding sharks, catch number of unidentified sharks, blue shark (*Prionace glauca*), salmon shark (*Lamna ditropis*), shortfin mako, common thresher (*Alopias vulpinus*), cookie-cutter shark (*Isistius brasiliensis*), pygmy shark (*Euprotomicrus bispinatis*), spiny dogfish (*Squalas suckleyi)*, white shark (*Carcharodon carcharias*), basking shark (*Cetorhinus maximus*), and smoothhounds (Triakididae) were recorded.

Catch estimation

Generally, same approach by Fujinami et al. (2021) was applied to the estimation of catch for SMA (detailed description and procedures are shown in the text and Fig.3 in the document). Standardized CPUE based on observer data (1990-1991) was estimated and then it was applied to the effort of logbook data (1981-1992).

Step 1. Standardization of CPUE

Compared to blue shark, zero catch ratio was high even in the observer data (99.6%). Thus, catch number was modelled using the assumption of negative binomial distribution. As observer data was available only two years, catch model focusing on location and quarter was developed based on observer data by applying GLM or GAM.

As the degree of overlap of data between observer and logbook data is not 100%, the logbook data was divided into several types; dataset with both location and quarter overlapped, dataset with only location overlapped, dataset with only quarter overlapped, and remaining dataset (no match). To estimate the coefficients of explanatory variables in the models for different combination of factors, we used four different model structures.

$\text{Catch} \cong \text{NB}(\mu, \theta)$

$\text{Model1}: \log(\mu) = intercept + factor(qt) + s(latitude, longitude) + offset(effort) + error$

$\text{Model 2}: \log(\mu) = intercept + s(latitude, longitude) + offset(effort) + error$

$\text{Model 3}: \log(\mu) = intercept + factor(qt) + offset(effort) + error$

$\text{Model 4}: \log(\mu) = intercept + offset(effort) + error$

, where Catch is catch in number, NB is a negative binomial model (error) with the mean μ and variance θ, the link function is log, the quarter (qt) was given as a fixed effect, the interaction of latitude and longitude was given using spline function and fishing effort was given as an offset term after transforming logarithm.

In this analysis, the fishing effort (total length in km of "tans") was defined through multiplying the number of "tans" by length of one tan. In the logbook data, length of tan was not available, standard length of tan (50m) was multiplied for the calculation of the effort. Regarding the effect of season, data between May and December was available in the observer data while data between January and April was very small in logbook data. Thus, data between May and December was divided into quarter 2 (May-June), quarter 3 (July-September), and quarter 4 (October-December).

Step 2. Model selection and evaluation

The models were run using the R software (version 4.2.3). Akaike Information Criterions (AIC) and Bayesian Information Criterions (BIC) were used to select the "best" model from the four models. The goodness-of-fits for the best model was also investigated using the residual plots, Q-Q plot and the fitting of the model to the data was evaluated.

Step 3. Estimation of catch

The estimated coefficients of explanatory variables (qt, latitude and longitude) and intercept of best model (based on scientific observer data) and corresponding fishing data (logbook data during 1981 to 1992) were used to predict the catch of SMA.

Other than this estimate based on "best model", catch was estimated based on other remaining models and remaining logbook data (excluding data used for prediction by best model), because the spatiotemporal coverage of logbook data was higher than that of scientific observer data and there was logbook data which did not overlap with observer data in terms of combination of "latitude-longitude-quarter" (used in the prediction of catch). Thus, remaining model was applied if the fishing area and/or quarter of logbook data was not covered by scientific observer data.

As subsequent estimation, model 2 (second lowest AIC/BIC) was applied to logbook data with same location data with observer data (catch based on model 2), and then model 3 was applied to remaining logbook data with same quarter in observer data (catch based on model 3). There was no data that conformed to none of the three types of datasets (corresponding to model 4). The predicted catches of SMA from the multiple models were aggregated by year.

Step 4. Conversion to the catch in weight from catch in number

Annual catches in weight of SMA were calculated using the predicted catch in number and average weight (38.2 kg) of SMA estimated from pomfret survey (details are described in Semba and Kai 2023b).

As preliminary estimate, uncertainty was estimated by two approaches. First, the standard errors of the annual catches were estimated under the assumption that the catch data for each operation were independent, and 95% confidence intervals were obtained. The other was to test the uncertainty in the estimated range by resampling the effort data of logbook 100 times with a non-parametric bootstrap.

Results

A total of 35,206 set was recorded in the observer data between 1990 and 1991. The catch number of SMA was 89 and 52 for 1990 and 1991, respectively, which were quite few compared to blue shark, reported to be 88,767 for 1990 and 95,356 for 1991. Correspondingly, zero catch rate (number of set with zero catch/ number of total set) of SMA (99.6%) was considerably higher than that of blue shark (46.3%). Between 1990 and 1991, the catch ratio to the total catch of sharks (in number) was highest for blue shark (93.7%), followed by salmon shark (5.2%) and that of SMA was 5th (0.03%) except for unidentified sharks (0.83%). The map of catch of SMA by year (Fig.1) and season (Fig.2) indicated that the catch was observed in offshore area (especially in the east of the dateline) and quarter 2.

In the comparisons among four NB models, both AIC and BIC selected the full model including qt, latitude, and longitude (Model 1 in Table 1) as the best model. In addition, the AICs and BICs of the remaining models showed that the performance of more complicated model was better than that of simpler model (Table 1).

The estimated annual catch (in number) from the best model based on observer data (only) was 81 for 1990 and 58 for 1991, respectively. The annual catch (in number) derived after combining estimates from all models were aggregated, ranged from 55 (1981) to 1,768 (1988), corresponding to 2.1 in 1981 to 67.6 ton in 1988 (Table 2). The estimated catch of "Japanese driftnet fishery" combining updated catch of large-mesh driftnet (Semba and Kai 2023b) and current estimate, was much lower than catch of F12 used in the previous assessment in 2018.

Discussion

Generally, annual trend of catch followed that of effort in that estimated catch increased since the early 1980s until mid-1980s and then decreased from 1988 to 1992 (Table2 and Fig. 3). Low catch in 1981 corresponded to low effort in this year, but it may be lower than actual annual catch if the effort in logbook is unreliable as described in Fujinami et al. (2021). Unlike in the case of blue shark, the increase of catch stopped at 1984 followed by stable catch until 1987 and then it peaked at 1988. The reason for this is unknown at present and left to be future work. The lower catch in 1990s was probably related to a decline in the number of active vessels, resulting decrease of deployed tans as described in Fujinami et al. (2021a).

Catch of SMA by squid driftnet fishery was much smaller than that of large-mesh driftnet (Table 3 in this document, Semba and Kai 2023b). As known, Japanese squid driftnet fishery changed the operation area historically; from operation in the coastal area in mid-1970's followed by expansion of fishing area to the eastward in 1980's (Yatsu et al. 1993). Large-mesh driftnet fishery was operated in both coastal and offshore area and majority of operation were observed in more southern area than those of squid driftnet fishery (see Fig. 2 in Semba and Kai 2023b and Supplementary Fig. S1 in the current document). In 1981, Japanese Government implemented the regulations that limit fishing season (1st June ~ 31th December) and fishing area (20º-46ºN, 170ºE-145ºW) for squid driftnet fishery with northern limit changed monthly from 40º-46ºN (Yatsu et al. 1993, Nagao et al. 1993). Compared to the distribution pattern of SMA estimated based on salmon research gillnet (Nakano and Nagasawa 1996) and longline data (Semba and Yokawa 2011), the overlap between effort distribution of commercial squid driftnet vessel and “core” distribution area of this stock, especially for juveniles, might have been small.

Estimated annual catches in weight ranged from 2.1 to 67.6 ton and combined catch with large-mesh driftnet fishery was much smaller than that (F12) used in the past stock assessment. The past estimates cannot be evaluated because detailed information on the materials and method was unknown. Estimate based on species composition ratio is one of the major approaches when there are little available data used for the analysis. As discussed in Semba and Kai (2023b), calculated ratio of SMA catch per that of blue shark based on past estimates was unreasonably high for driftnet fishery, thus, the past catch of SMA of this fishery used for the stock assessment is likely to be overestimate.

In this revision of SMA catch, statistical approach was applied using logbook (after effort correction) and observer data, following Fujinami et al. (2021a). Preliminary estimate of uncertainty suggests unreasonably wide confidence interval in the first approach, while very low confidence interval in the other approach. For the first approach, assumption of independence of each set might have caused large variance, while variability of effort was much smaller than expected in the other approach. There may be also uncertainty in the current estimate, due to the limited observer data and resulting irregular approach. Even with such uncertainty, a series of analysis and associated information in the current document, suggest that the amount of catch of SMA caught by squid driftnet fishery before 1993 was not large compared to that of large-mesh driftnet fishery. In addition to the catch of large-mesh driftnet fishery (Semba and Kai 2023b), current estimates by Japanese squid driftnet fishery can be used as the input data for the upcoming stock assessment of SMA in the North Pacific Ocean. Considering the impact of this fishery in the early period is high (ISC Shark Working Group 2018), it is necessary to continue the improvement of estimation of mortality by this fishery.

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Table1 Explanatory variables, AIC and BIC for four models analyzed.

Model	Explanatory variables	AIC	BIC
Model 1	+ qt + latitude + longitude	1618.4	1812.6
Model 2	+ latitude + longitude	1623.1	1787.8
Model 3	+qt	1732.0	1765.8
Model 4	Intercept	1784.7	1801.6

Table 2. Estimated catch (in number and weight) of SMA by squid driftnet fishery between 1981 and 1992. Estimated catch by large-mesh driftnet fishery and aggregated catch (in weight) of SMA by "Japanese driftnet fishery" between 1975 and 1992 were also shown.

	Squid DN Estimates	Squid DN Estimates	Large mesh Approach 3	Total DGN	Catches (F12) used in the stock assessment (2018)
	number	ton	ton	ton	ton
1975			200.0	200.0	1,329
1976			368.3	368.3	1,329
1977			606.5	606.5	1,329
1978			370.5	370.5	1,329
1979			274.5	274.5	1,329
1980			199.3	199.3	1,329
1981	55	2.1	195.5	197.6	4,142
1982	601	23.0	195.8	218.8	4,142
1983	935	35.7	147.3	183.0	4,064
1984	1329	50.8	160.4	211.2	3,810
1985	1183	45.2	154.5	199.7	3,607
1986	1365	52.2	171.8	224.0	3,674
1987	1122	42.9	153.0	195.9	3,655
1988	1768	67.6	126.4	193.9	3,595
1989	1404	53.6	105.2	158.9	5,007
1990	787	30.1	105.4	135.5	2,630
1991	854	32.6	125.5	158.1	2,630
1992	477	18.2	118.7	136.9	1,639

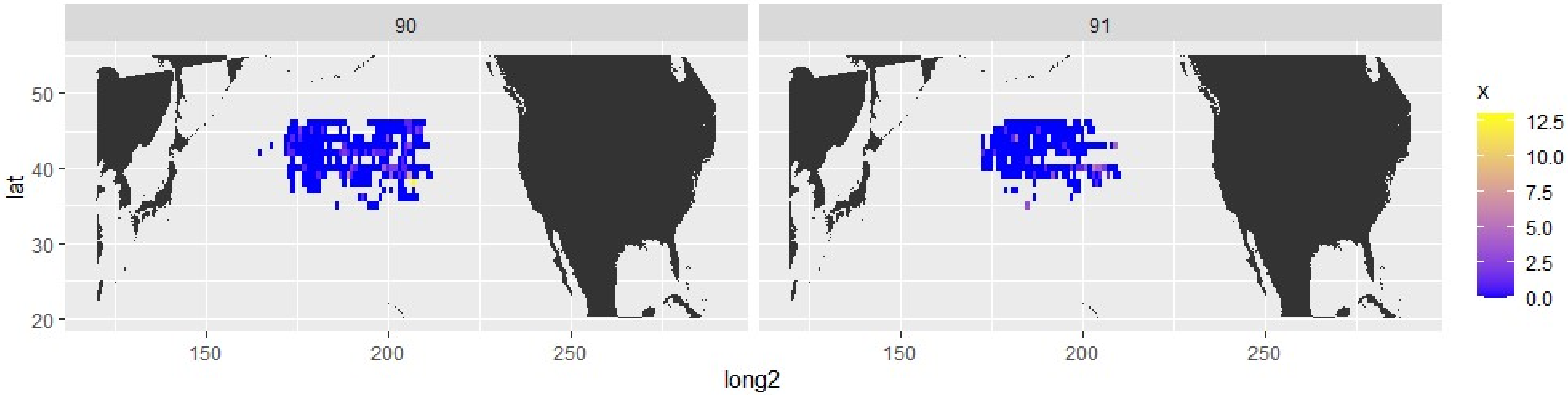

Fig.1 Annual distribution of catch (in number) of SMA recorded in observer data between 1990 and 1991.

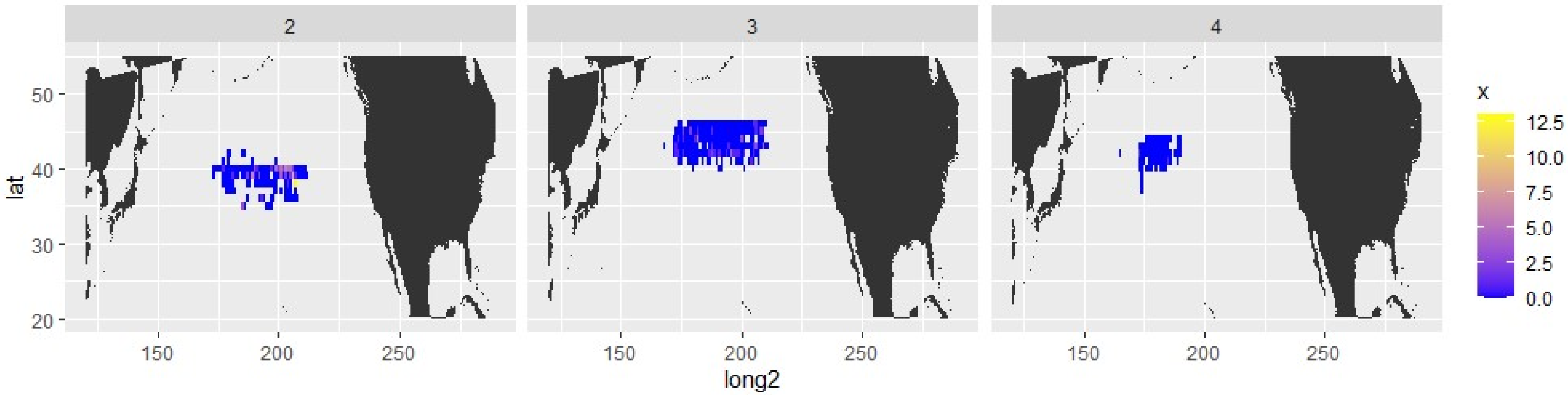

Fig.2 Seasonal distribution of catch (in number) of SMA recorded in observer data between 1990 and 1991.

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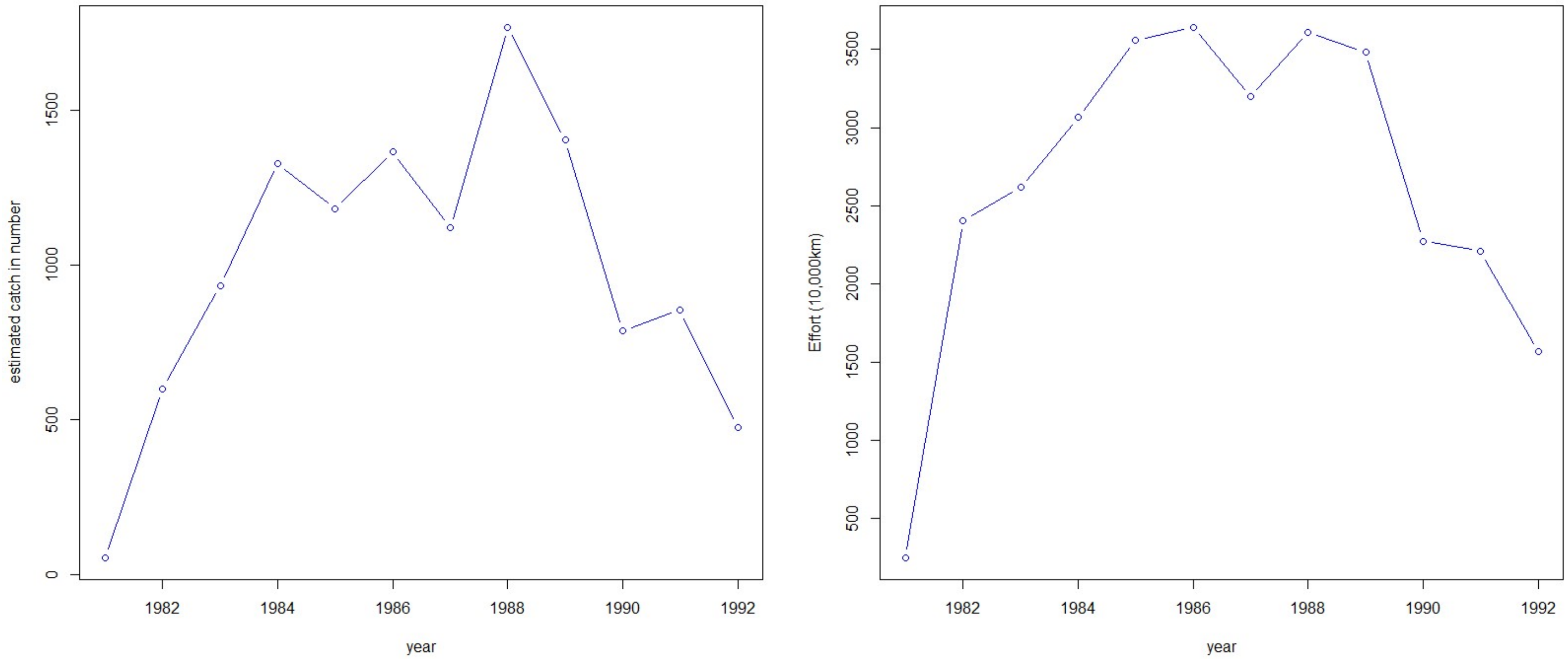

Fig.3 Annual estimate of catch in number of SMA caught (left) and effort (right) by squid driftnet fishery between 1981 and 1992.

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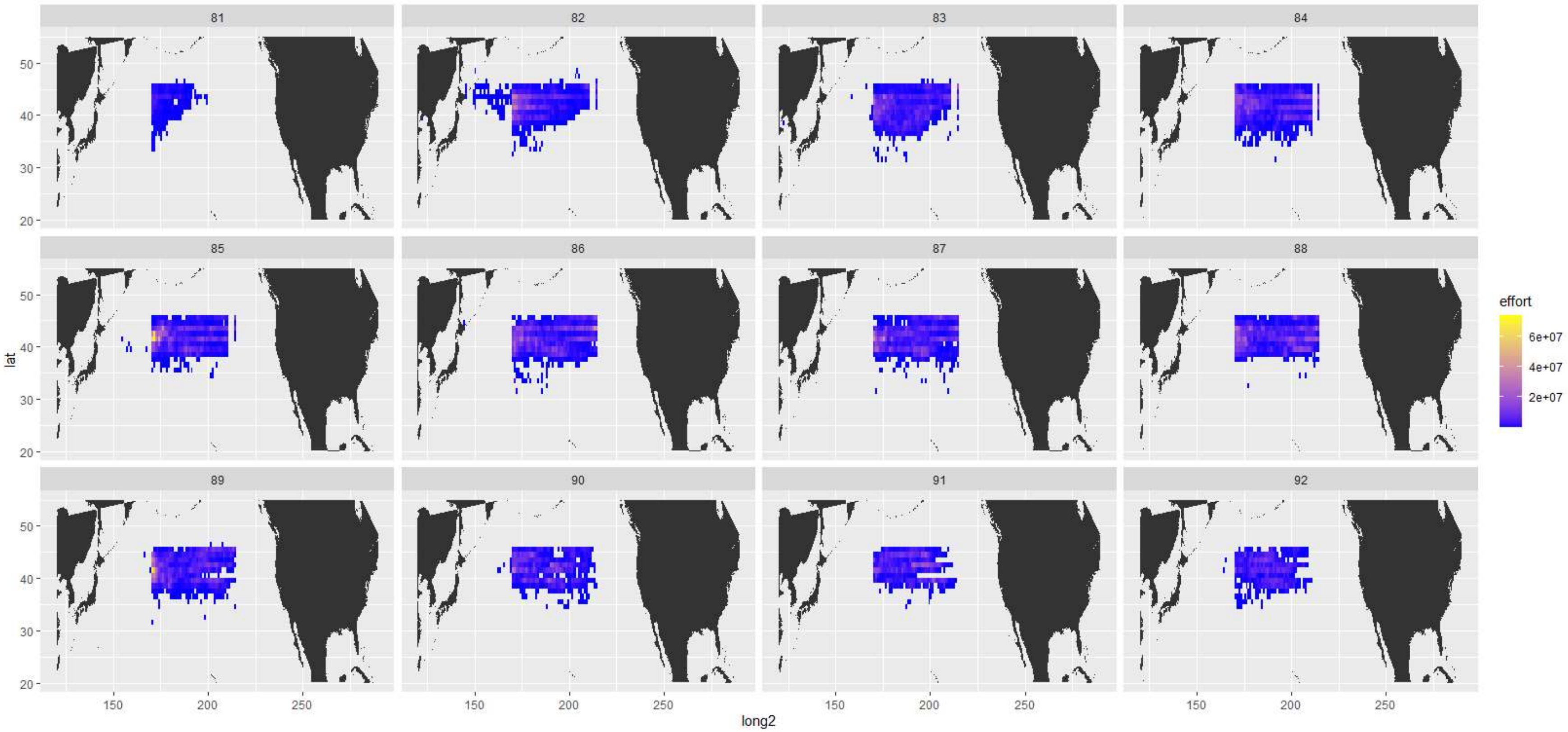

Supplementary Fig. 1 Annual distribution of effort of squid driftnet fishery from logbook data between 1981 and 1992.

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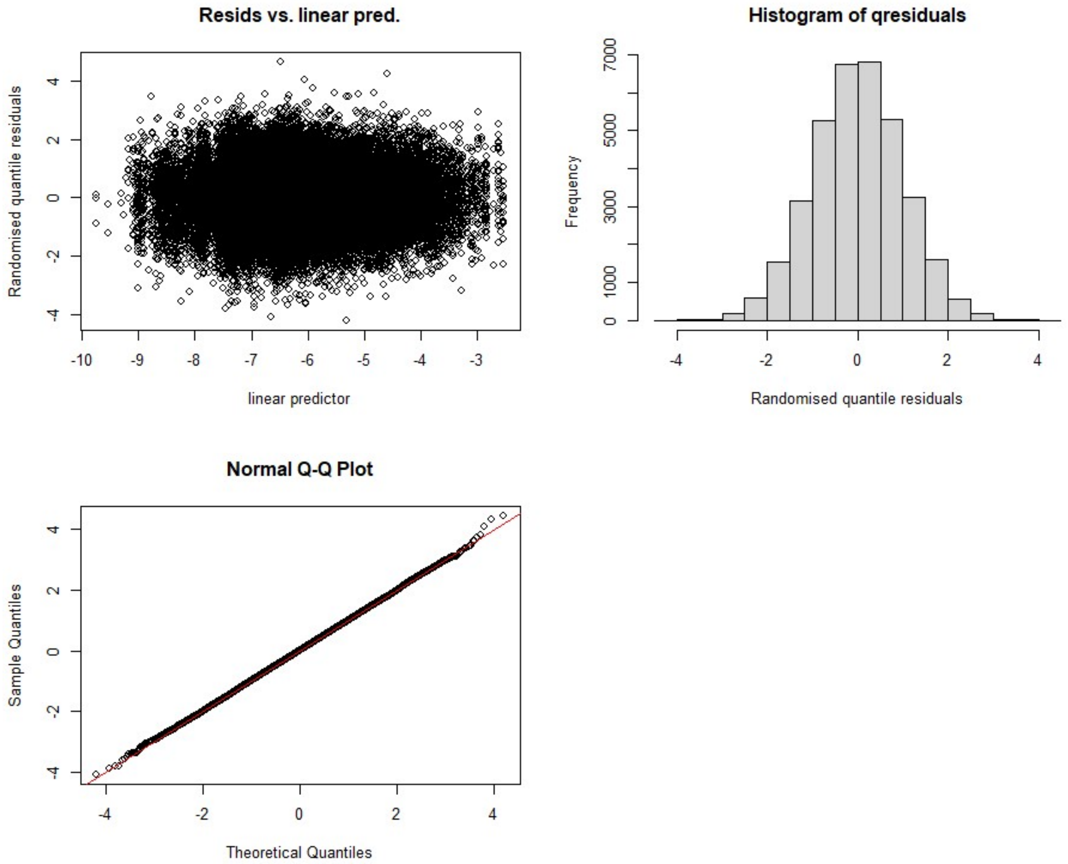

Supplementary Fig. 2 Diagnostics of goodness-of-fits for the outputs of GAM analysis for model 8 (best model) with negative binomial error distribution.

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Appendix. Summary of goodness-of-fits for the outputs of GAM analysis for model 8 (best model)

Family: Negative Binomial (0.077)
Link function: log

Formula:
t.catch.105 ~ factor(qt) + s(lon, lat) + offset(log(effort))
Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-15.5530	0.3655	-42.547	<2e-16	***
factor(qt)3	0.8442	0.4573	1.846	0.0649	.
factor(qt)4	-0.1870	0.8427	-0.222	0.8244	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value	
s(lon,lat)	17.29	21.83	121	<2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =0.0132 Deviance explained = 21.2%
-REML = 814.68 Scale est. = 1 n = 35191

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